Generation of quasi-steady and steady state PR solitons in an optically active crystal

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We present experimental results on stable self-focused states and quasi-steady solitons in an optically active PR crystal (BTO) with a lifetime of several hours. Choosing the appropriate polarization of the signal beam the disturbing effects of the optical activity can be avoided.

1 Introduction

Photorefractive (PR) solitons, self-focusing and defocusing of single laser beams have been studied in a variety of materials in the past two decades. PR solitons have the advantage to build up at very low intensities (mW/cm^2). They are also of great interest because of their potential towards some important applications in photonics and optics communications. Spatial solitons can be used either for adaptive or fixed structuring of nonlinear materials. A stable, predictable, and reproducible spatial soliton formation process is therefore mandatory and is studied here for the case of $Bi_{12}TiO_{20}$ (BTO).

We report on experimental verifications of stable self-focusing in a $Bi_{12}TiO_{20}$ crystal at $\lambda = 633$ nm. BTO belongs to the sillenite type crystals that exhibit optical activity (OA). OA rotates the plane of linear polarization of the wave propagating through the material. In a strict sense, then no spatial soliton formation can occur [1].The rotary power is 6.3°/mm at 633 nm. However, the sample we used is a so-called fiber-like crystal, which is long in the propagation direction (21.24 mm) and very small perpendicular to it (0.89 mm). This leads to a total polarization rotation of 134°. Therefore, the influence of the polarization on the effective electro-optic coefficient r_{eff} and hence the self-focusing effect must be taken into account. We use circular polarization of the laser beam. This leads to a r_{eff} that is indeed constant over the whole propagation distance. Thus, the beam experiences approximately the same nonlinearity throughout the crystal.

2 Experiments

A HeNe laser beam is focused onto the entrance face of the crystal to a spot size of about 30 µm [2]. The light propagates along its longest dimension ([110]) and the external electric field is applied along the shortest one ([1-11]). To raise artificially the dark irradiance the crystal is illuminated uniformly by white light. The output beam peak intensity as well as the beam widths parallel and perpendicular to the external field are measured. We determine the beam diameter at the crystal's back facet in regular intervals to observe its temporal development.

We investigate the dependence of the temporal development of the beam width $w(t)$ on two parameters: the intensity ratio r, which is the quotient of the beam peak intensity in the steady state and the artificially raised dark irradiance I_d, and the external field E_0.

Furthermore, for some chosen parameters (r, E_0), the influence of the polarization direction and the polarity of the applied voltage on the self-focusing is investigated.

3 Results

In Fig. 1, the dependence of the time (t_{min}) to reach the minimum beam width on the externally applied field is depicted for different intensities of the input beam. Only the first minimum is taken into account, even if there exists a quasi-steady

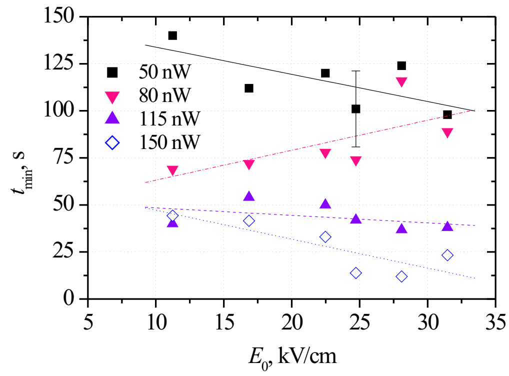

Fig. 1 *Time to reach a minimum beam diameter as a function of E_0 for different signal beam intensities.*

state. The focusing time does not depend on the external field, within the imposed accuracy limits. An uncertainty are, for example, different establishment times of the photorefractive effect during measurement series due to the light induced absorption of BTO.

The time t_{min} is only determined by the ratio r of the beam peak intensity and the background intensity since this latter one is kept constant. This behaviour is in good agreement with the theory.

Next we consider the self-focusing power α. It is the quotient of the beam widths in the focused state and in the normal diffraction regime, $\alpha = w(t)/w(0)$, parallel to the external field. α = 1 means

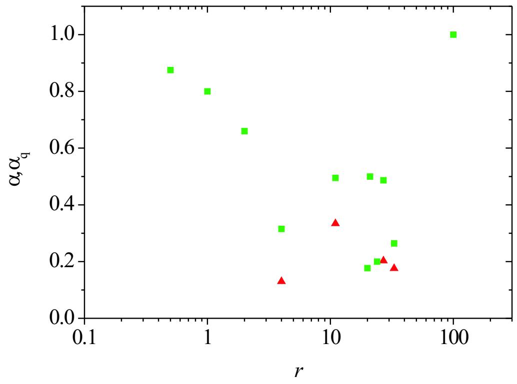

Fig. 2 *Self-focusing power as a function of the intensity ratio in the transient (alpha_q) and steady state (alpha).*

that no self-focusing takes place. In Fig. 2, α as a function of r is traced. We distinguish between the transient and the steady state soliton's width. For small values of r no quasi-steady focusing occurs, which fits well into calculations carried out, for example, in [3]. Then a transient state appears. Around r = 30, no quasi-steady soliton could be observed, as well as for r = 100 though it is predicted by the theory.

One reason for the strong scattering of α in the soliton region and the nonexistence of a quasi-steady state could be the memory effect of the crystal. Due to its strong light induced absorption around 500 nm the photore-fractive effect (saturation and dielectric relaxation time) could have been influenced by a prior illumination with a green laser.

By determining r a considerable error can be made. It is mainly due to the error linked to the dark intensity I_d. This latter is measured only in a small area around the signal beam and therefore possible inhomogeneities outside the observed field cannot be taken into account.

With our experimental set-up only one configuration allows for efficient self-focusing (Fig. 3). We perform measurements of the temporal development of the peak intensity I_P at the end face of the BTO crystal for $r \approx 4$ and E_0 = 28.1 kV/cm. The polarity of the external voltage was turned as well as the polarization, which was changed from right to left circular. The "standard" combination with which all experiments were carried out consists of right circular polarization of the signal beam and "+" polarity of the electric field.

The self-focusing effect is strongly developed. If the polarization is changed to left circular a very slight defocusing can be observed; the same happens if additionally the polarity is reversed. Finally, for right circular polarization and "-" polarity a very weak focusing of the beam can be stated. This means that the nonlinearity has the same sign as in (1) but is based on a much smaller effective electro-optic coefficient.

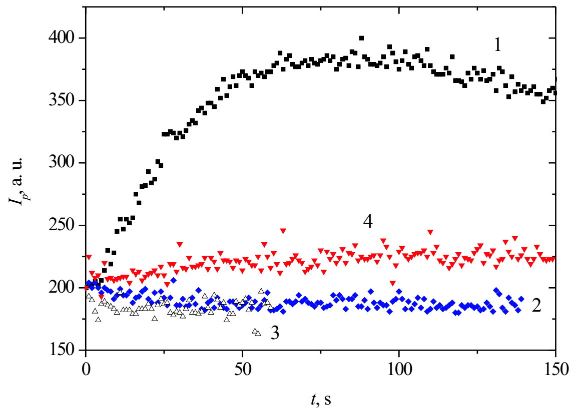

Fig. 3 *Temporal development of I_P for 1 – right circular polarization (rcp) and polarity "+"; 2 – left circular polarization (lcp) and "+"; 3 – lcp and "-"; 4 – rcp and "-".*

During the experiments we found that to successfully generate stable self-trapped beams it is mandatory to adjust the background illumination such that its intensity distribution is as uniform as possible. Furthermore, there exists a very restricted value range within which the background illumination can be varied. For example, if there is no or a very weak white light illumination, the beam tends to split up into two or three filaments with complicated dynamics. The same applies to high signal beam powers (> 0.5 µW, depending on the external electric field).

4 Conclusions

We presented experimental results on self-focusing in an optically active BTO crystal. We observed a self-focused beam over several hours. The temporal development of the soliton and the self-focusing power for different electric fields and intensity ratios were investigated. The existence of the quasi-steady state depends on external and crystal parameters which have to be studied yet. The strong asymmetry in the steady state is due to the anisotropy of the photorefractive effect.

References

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